THE DEVELOPMENT AND ASSESSMENT OF ALKALI ACTIVATED PAVING BLOCKS

ANA FRANKOVIČ,[1] VILMA DUCMAN,[1]
LUBICA KRISKOVA,[2] EFTHYMIOS TATSIS,[2]
PETRICA PETRICA,[2] YIANNIS PONTIKES[2]

[1] Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia
ana.frankovic@zag.si, vilma.ducman@zag.si
[2] KU Leuven, Department of Materials Engineering, Leuven, Belgium
lubica.kriskova@kuleuven.be, efthymios.tatsis@kuleuven.be, petricapetrica1@gmail.com
yiannis.pontikes@kuleuven.be

Abstract In recent years great attention has been placed by the building sector on alkali-activated technology based on metakaolin, fly ash and ground granulated blast furnace slag (GGBFS), but also on emerging precursors such as by-products from non-ferrous metallurgy. The present work focuses on the development of alkali-activated binders from two slags, one from primary and one from secondary copper production, which were finely milled, blended with GGBFS, and activated with K-based alkali silicate solution with a 1.7 SiO2/K2O molar ratio. The aggregate to paste mass ratio was 2. The mixtures were cast, and cured for a designated time at room temperature and 60% RH. The so-obtained paving blocks were then tested in accordance with European standard for concrete paving blocks. The following properties were measured: splitting tensile strength, abrasion resistance, slip and skid resistance, resistance to freeze-thaw and resistance to freeze-thaw in the presence of de-icing salts. Their properties were compared to those of commercially available concrete paving blocks, and it was found that the performance of the alkali-activated pavers was generally comparable with the concrete pavers, while certain properties (e.g., abrasion resistance, freeze-thaw resistance and freeze-thaw resistance in presence of de-icing salts) were considerably better.

Keywords:
Cu slag,
alkali activation process,
pavers,
properties,
durability

University of Maribor Press

DOI https://doi.org/10.18690/um.fkkt.2.2022.1
ISBN 978-961-286-598-6

1 Introduction

One of the main objectives of the circular economy is to reduce the overuse of the available raw materials in order to restore ecological balance. This can be achieved by replacing raw materials with industrial waste or by-products. The greatest potential is seen in construction sector which consumes 35-45 % of natural resources [1].

Alkali-activation technology has been recognized as a promising method for the utilization of wastes and industrial by-products which are rich in silica and aluminium. The type of waste and by-products mentioned can therefore be used as a precursor in alkali-activated technology and converted into valuable building and construction materials such as binders, concrete, mortar, paving blocks, and bricks, thereby reducing demand for, and the subsequent environmental impact of, the production of Ordinary Portland Cement (OPC) [2]. In order to produce high quality building products, the composition of the alkali-activated mixture must be properly adjusted. Van De Sande et al. show that the chemical and mineralogical composition of non-ferrous slags used as precursors for alkali-activation play an important role in the mechanical and physical properties of the final product, and that the type of activator affects the kinetics and strength at an early age of the final product [3]. Furthermore, it was shown that using a proper rate of cooling when solidifying the non-ferrous slags led to the formation of a higher content of amorphous phase, and consequently to the formation of a solid alkali-activated binder [4].

One promising final uses for alkali-activated binders with a high residue content is the production of paving blocks. When processing new products, the aim is to develop products which have better, or at least comparable properties, to products already established on the market. The literature shows some cases where alternative materials, such as paving blocks, have been successfully made using alkali-activated technology. For example, Tatarannni et. al. successfully used waste basalt powder as a precursor in an alkali-activated binder for the production of alternative paving blocks [5]. Furthermore, Hossiney et. al. synthesized alkali-activated paving blocks using a high residues content in both the precursor (fly ash and ground granulated blast furnace slags) and the aggregate (recycled asphalt pavements) [6].

This paper presents an alternative alkali-activated binder developed from non-ferrous metallurgy slag, used in up-scale production of paving blocks, intended for implementation in sustainable urban areas. Since there are no standards available for newly developed alkali-activated products, the performance of the paving blocks developed was evaluated according to standard EN 1338: Concrete paving blocks - Requirements and test methods [7].

2 Experimental

2.1 Materials

Finely milled (approximately 4000 cm^2/g Blaine surface area) iron rich mineral formed during/ after secondary Cu production, i.e. Koranel® (Metallo Belgium N.V), was used in the present study. Its chemical composition is given in Table 1; its mineralogical evaluation confirmed the highly amorphous nature of the precursor, which contains 92 % amorphous phase and 8 % of the mineral Hercynite.

Table 1: Chemical composition of the materials, in wt%

Oxide	FeO	SiO_2	Al_2O_3	CaO	ZnO	MgO	SO_3	Na_2O	CuO	Others
Koranel®	51	25	8	3	6	1	<1	<1	<1	3

2.2 Production

The paving tiles were produced by blending Koranel® with GGBFS in a 6:1 mass:ratio and activated with a K- based alkali silicate solution (SiO_2/K_2O molar ratio of 1.7 and water content of 65 wt%), bringing the solution to a powder mass ratio of ~ 0.4. The aggregates and additives were gradually added into the activating solution and the final blend was mixed at high speed for approximately 2 min in a Hobart mixer. The fresh mortars were cast into moulds and cured for a designated time at RT and 60% RH.

Figure 1: The production process of the alkali activated paving blocks
Source: authors from KU Leuven

2.3 Methods

The paving blocks developed were tested with respect to their intended use, following the specifications outlined in standard EN 1338: Concrete paving blocks - Requirements and test methods [7]. The testing method for freeze-thaw resistance was adopted according to the standard ASTM C666 / C666M – 15: Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing [8].

The following parameters were simultaneously determined for both the Koranel®-rich paving blocks developed and for the reference material, a commercial product widely used in urban paving:

- slip and skid resistance,
- abrasion resistance,
- splitting tensile strength,
- freeze-thaw resistance,
- freeze-thaw resistance in the presence of de-icing salts.

Since the number of samples was limited, some adjustments were made when performing the splitting tensile strength test. As shown in Figure 2, the samples were oriented differently so that two halves could be obtained in order to implement further test methods.

Figure 2: Adjustment in the performance of the splitting tensile strength test.
Source: own.

3 Results and discussion

The test results are shown in Table 2. As can be seen from the results, the slip and skid resistance coefficient (Pendulum Test Value – PTV) is highly dependent on the nature of the surface; it is generally higher on the upper side, while it is very smooth with much lower values on the bottom side, where it had been in contact with the mould. On Rubber 57 under wet conditions, the PTV of the Koranel®-rich samples was 29 at the side which had been in contact with the mould, and 56 at the upper face within the mould. The reference material attained a value of 69. It should be noted that this characteristic could be significantly influenced simply by making a relief of the surface of the mould during the production phase.

When determining abrasion resistance, the length of the groove of the Koranel®-rich paving blocks was 17.6 mm, compared to 22.1 mm in the reference material (Figure 3). According to the standard, permissible values for the abrasion resistance of concrete paving blocks have not been specified. From the literature, however, it can be seen that natural stone reaches values from 14.8 mm for granite to as high as 27.3 in limestone [9].

Table 2: The performance of alkali activated paving blocks compared to the commercial concrete paving blocks

Parameter	Unite/conditions	Koranel®-rich	Reference material
Slip and skid resistance (PTV) (Top/bottom)	Rubber 57 – Wet	29/56	69
Abrasion resistance	mm	17.6	22.1
Splitting tensile strength	MPa	9.5	4.0
Freeze-thaw resistance	After 300 cycles (-20°C/9°C)	Resistant	Not resistant
Freeze-thaw resistance in presence of de-icing salts	After 25 cycles (3% NaCl; -20°C/20°C)	Resistant	Not resistant

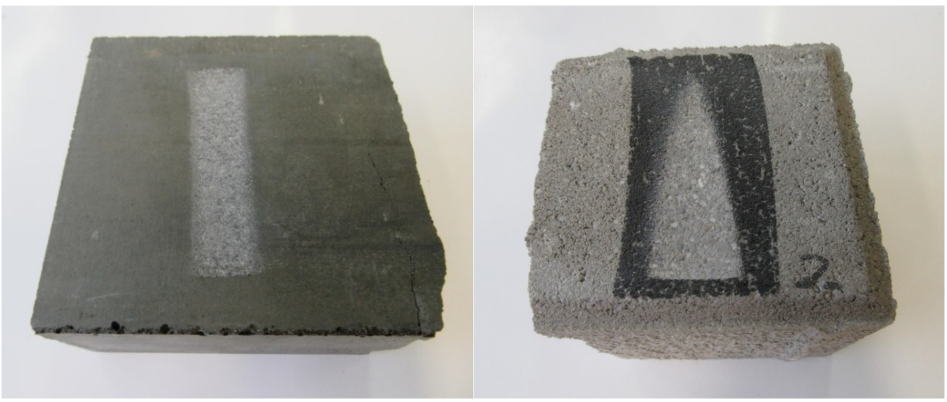

Figure 3: Abrasion resistance of the Koranel® sample (left) and the reference material sample (right)

Source: own.

As mentioned above, the splitting tensile strength test method was modified. The results obtained showed that the Koranel®-rich paving blocks exhibited a splitting tensile strength of 9.5 MPa, which is higher than that of the reference material, which reached 4 MPa.

Furthermore, freeze-thaw resistance was monitored by measuring the resonant frequency, as shown in Figure 4. The results show that breakage of the internal structure begins in the reference material after about 80 freeze-thaw cycles. After 300 freeze-thaw cycles there was visible deterioration in the reference material, while the Koranel®-rich paving blocks remained unchanged (Figure 5).

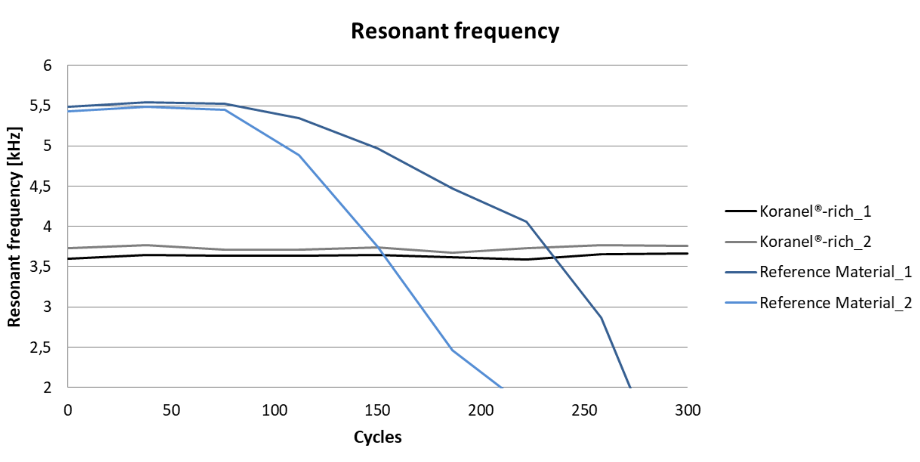

Figure 4: Resonant frequency after 300 freeze-thaw cycles
Source: own.

Figure 5: Freeze-thaw resistance after 300 cycles; Koranel®-rich sample (left) and the reference material (right)
Source: own.

A similar trend was seen when determining the freeze-thaw resistance of the materials in the presence of de-icing salt. The Koranel®-rich paving blocks showed no deterioration after 25 freeze-thaw cycles (freezing at – 20 °C and thawing at 20 °C), while cracks appeared on the surface of the reference material after 20 cycles (Figure 6).

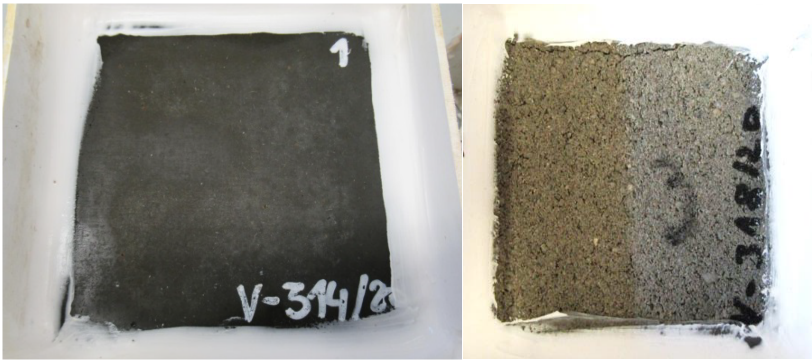

Figure 6: Results of freeze-thaw resistance tests in the presence of de-icing salts; Koranel®-rich sample after 28 freeze-thaw cycles (left), and the reference material after 20 cycles (right)
Source: own.

4 Conclusions

Slags generated from the production of various metals were successfully utilized for the production of paving blocks. The performance of blocks obtained in such a way was compared to commercially available concrete paving blocks, and it was confirmed that the performance of the alkali-activated pavers was on a par with the concrete pavers, with certain properties being notably better:

- Koranel®-rich samples were resistant to over 300 freeze-thaw cycles,
- Koranel®-rich samples also exhibited resistance to freezing and thawing in the presence of de-icing salts,
- the splitting tensile strength of the alkali-activated samples was twice as high as that of the concrete paving blocks,
- abrasion resistance was highest in the Koranel®-rich based paving blocks.

The technology developed could therefore be successfully implemented in the building sector, providing both the benefit of using waste instead of virgin materials, thus saving resources, and lowering the potential of global warming by replacing cement with alternative binders. Such a solution is completely in alignment with our present-day paradigm of promoting industrial symbiosis and a circular economy.

Acknowledgement

"This activity has received funding from EIT RawMaterials, a Knowledge and Innovation Community (KIC) of the European Institute of Innovation and Technology (EIT), a body of the European Union, under Horizon 2020, the EU Framework Programme for Research and Innovation. Project Agreement No. 16365 (RECOVER), project website: https://recover.technology."

References

[1] P. Mhatre, V. Gedam, S. Unnikrishnan, S. Verma, Circular Economy in Built Environment – Literature Review and Theory Development, Journal of Building Engineering, https://doi.org/10.1016/j.jobe.2020.101995.
[2] Singh, J., & Singh, S. P. (2019). Geopolymerization of solid waste of non-ferrous metallurgy – A review. Journal of Environmental Management, 251, 109571. doi:10.1016/j.jenvman.2019.109571
[3] Van De Sande, J., Peys, A., Hertel, T., Rahier, H., & Pontikes, Y. (2020). Upcycling of non-ferrous metallurgy slags: Identifying the most reactive slag for inorganic polymer construction materials. Resources, Conservation and Recycling, 154, 104627. doi:10.1016/j.resconrec.2019.104627
[4] Pontikes, Y., Machiels, L., Onisei, S., Pandelaers, L., Geysen, D., Jones, P. T., & Blanpain, B. (2013). Slags with a high Al and Fe content as precursors for inorganic polymers. Applied Clay Science, 73, 93–102. doi:10.1016/j.clay.2012.09.020
[5] Tataranni. (2019). Recycled Waste Powders for Alkali-Activated Paving Blocks for Urban Pavements: A Full Laboratory Characterization. Infrastructures, 4(4), 73. doi:10.3390/infrastructures4040073
[6] Hossiney, N., Sepuri, H. K., Krishna Mohan, M., R, A. H., Govindaraju, S., & Chyne, J. (2019). Alkali-activated concrete paver blocks made with recycled asphalt pavement (RAP) aggregates. Case Studies in Construction Materials, e00322. doi:10.1016/j.cscm.2019.e00322
[7] EN 1338: Concrete paving blocks - Requirements and test methods.
[8] ASTM C666 / C666M – 15: Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing.
[9] Karaca, Z., Günes Yılmaz, N. & Goktan, R.M. (2012). Considerations on the European Standard EN 14157 Test Methods: Abrasion Resistance of Natural Stones Used for Flooring in Buildings. Rock Mech Rock Eng 45, 103–111. https://doi.org/10.1007/s00603-011-0190-1